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A broadband and dual-polarization single-layer dichroic filter for applications in Sub-THz range

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***Abstract*— In this work we report the design of a single-layer all-metall dichroic filter with an improved spectral response at non-normal beam incidence and nearly equal performance for both polarizations. The dichroic is intended to be employed for dual-frequency receivers. Since the dichroic is produced purely from metal it facilitates its use at cryogenic temperatures. Therefore, the contribution to the system noise is minimized. The dichroic design concept demonstrated a measured transmission of electromagnetic radiation of 85-90% for both polarizations in the range of 35-50 GHz (37% fractional bandwidth). The measurements were performed at room temperature. The spectral properties of the dichroic have been optimized by modeling in 3D FEM simulation software.**

***Keywords*— dichroic, filters, mm-wave**

I. INTRODUCTION

Frequency-selective surfaces (FSSs) are widely used as dichroic quasi-optical filters, which allow either dividing a beam into two based on the frequency difference or combining beams from different sources generating different frequencies into a single beam for further processing. The idea of spacially dividing a beam is commonly found in astronomical applications since it has enabled the deployment of multi-band receivers for radio astronomy, multi-pixel systems for current and future facilities on Earth, and stratospheric and space astronomy missions [1,2]. There are numerous benefits of multi-pixel and multi-frequency receiver systems since they allow for increasing the mapping speed and spectral line surveys. Additionally, multi-frequency enhances the phase calibration in high-frequency interferometric observations. Furthermore, the multi-frequency receiver systems have the potential to provide unique information for future Very Large Baseline Interferometry (VLBI) observations [3]. All above, along with the continuous demand for improved instrument sensitivity, explains the increasing interest in developing state-of-the-art dichroic filters.

Traditionally, a dichroic filter employs a sequence of several patterned metallic and dielectric layers, making the devices inherently sensitive to the control of linear dimensions of the pattern elements of each layer and the layers' separation [4]. In fact, the geometrical properties such as the patterns' shapes and sizes, their periodicity, and the thickness of the metal and dielectric layers determine the frequency response of any dichroic. Therefore, complicated configurations are utilized for improving different relevant aspects, such as transmission stability, cross-polarization levels, increasing the bandwidth, or reducing the angular degradation [5].

In this work, we present a novel design and technologically simpler concept for dichroic filters using a single metallic layer. The plate is perforated at an angle of θ=13 degrees with the perforation shape optimized to reduce the insertion loss, frequency response, dual-polarization capability, and operational bandwidth.

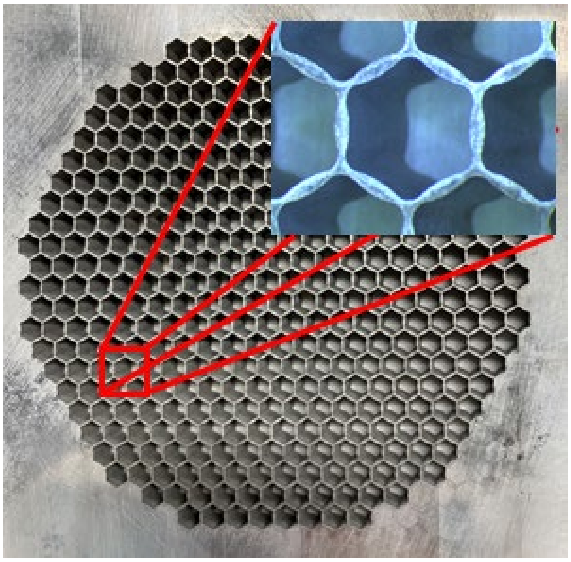

Fig. 1 Dichroic array showing an hexagonal layout.

II. DESIGN, SIMULATIONS, AND CHARACTERIZATION

We have chosen to confirm the design feasibility and fabrication of the filter in the Q-band (35-50 GHz) as it could be further used in a VLBI Tri-band receiver planned for Onsala Space Observatory 20 m antenna. However, since the single-layer metal structure is used, the FSS filter is perfectly scalable to higher frequency bands and fabrication with, e.g. microfabrication techniques [6]. The proposed design is a single-layer FSS based on a metallic plate with tilted perforations of customized geometry as shown in Fig1. The unit hexagonal cells are depicted in Fig. 1 insert. The spectral response of a dichroic filter is determined by its geometrical parameters, i.e., the shape and size of the apertures, the aperture spacing, the thickness of the metal layer, and how the layers are arranged (in the case of multi-layer systems). The transmissivity and reflectivity of a dichroic filter also depend on the polarization orientation (horizontal or vertical) of the incoming electromagnetic wave and the angle of incidence, θ (AOI). The latter at non-normal beam incidence (e.g. θ≠0), affects the dichroic performance in a form known as angular degradation. Typically, this degradation causes a reduction of the RF bandwidth, shifting in the frequency cut-off, resonance spikes in the pass-band, and increased levels of cross-polarization [7]. The AOI of θ = 13 degrees was aimed to be acceptable for the telescope optical systems as well as because of feasibility for the filter's manufacturing that is critical for achieving desired performances. A

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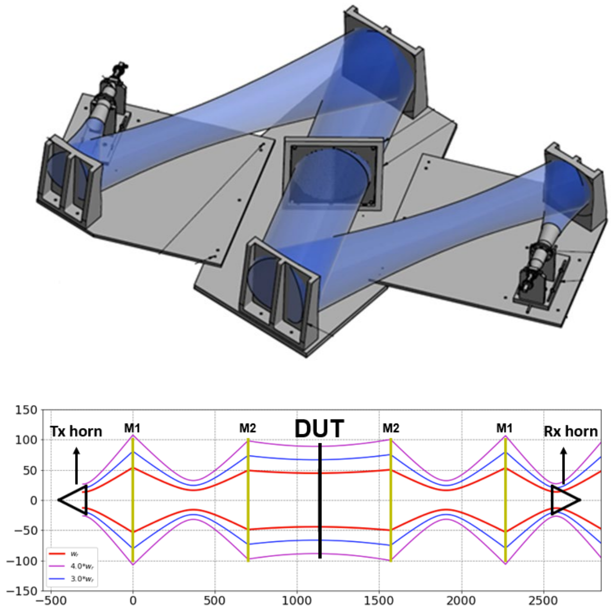

Fig.2. Designed optical system to characerize the dichroic filter. (Top) 3D sketch of the optical assembly, the blue-shaded volume corresponds to the calculated quasi-optical beam. (Bottom) Optical train calculation for a beam at 42.5 GHz..

hexagonal units cell array was chosen for its higher mechanical stability, however, at the expense of having a somewhat reduced bandwidth.

Simulations of the dichroic filter and its optimization were performed using HFSS simulation software. Measurements of transmissivity of the fabricated filters as a function of frequency were carried out using a quasi-optical setup shown in Fig.2. Two spline-profile horns optimized for the Q-band frequency range are connected to a VNA and used as a transmitter (Tx) and a receiver (Rx) for the optical system consisting of 4 active mirrors. During the measurements dichroic filter (DUT) was placed across the collimated beam between the two M2 mirrors (see Fig. 2). The polarizations grids in front of the horns were implemented to improve the quality of the cross-polarization measurements.

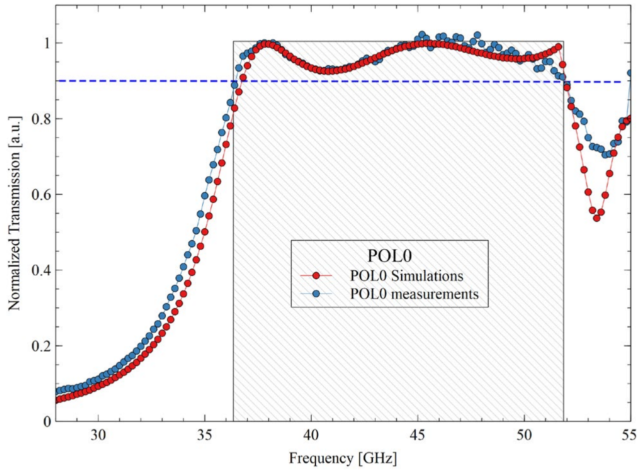

Fig.3 Simulated and measurement performance of the designed dichroic filter at the AOI of 13 degrees for one of polarization with *horizontally* oriented E–field (POL0). Red and blue color circles corresond to transmission .The partly filled region illustrates the frequency range between 37 and 52 GHz where the transmittion is over 90% marked with a blue dashed horizontal line.

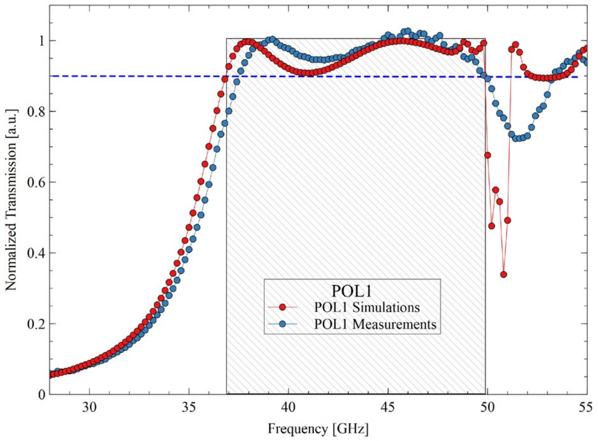

Fig.4 Simulated and measurement performance of the designed dichroic filter at the AOI of 13 degrees for one of polarization with *vertical* oriented E–field (POL1). Red and blue color circles corresond to transmission .The partly filled region illustrates the frequency range between 37 and 50 GHz where the transmittion is over 90% marked with a blue dashed horizontal line.

The simulated and measured performances of the designed dichroic filter at $\theta=13$ degrees are presented in Fig.3 for POL0 and Fig.4 for POL1. Red and blue color circles correspond to co-polar transmission, and the cross-hatched region indicates a frequency range where the transmission is over 90%, the level marked with a blue dashed horizontal line. As could be seen, the results of the measurements are in good agreement with the simulated data, especially for POL0, demonstrating a fractional bandwidth of 37%.

III. CONCLUSION

We have proposed a novel design for the dichroic filter based on a perforated metal plate. The proposed design can reach 90% of the transmission in at least 37% of the RF bandwidth around 42 GHz central frequency. The measured performance showed a very good agreement with the simulations for both polarization. The presented design is scaleable to higher frequencies and could be employed as a cold dichroic filter for providing simultaneous operation at higher frequencies, for instance, e.g. 230 and 345 GHz channels of the Event Horizont Telescope.

IV. REFERENCES

[1] I. Mehdi, et al., “Far-infrared heterodyne array receivers”, *Bulletin of the American Astronomical Society*, vol. 51, no. 7, 2019.

[2] M. C. Wiedner et al., "A Proposed Heterodyne Receiver for the Origins Space Telescope," *IEEE Transactions on Terahertz Science and Technology*, vol. 8, no. 6, pp. 558-571, Nov. 2018.

[3] M. J. Rioja et al. “The Power of Simultaneous Multifrequency Observations for mm-VLBI: Astrometry up to 130 GHz with the KVN”, *The Astronomical Journal*, 150.6 (2015), p. 202.

[4] Xiaolong You, Christophe Fumeaux and Withawat Withayachumnankul, “Tutorial on broadband transmissive metasurfaces for wavefront and polarization control of terahertz waves”, J. Appl. Phys. 131, 061101 (2022); https://doi.org/10.1063/5.0077652.

[5] D. Montofre, et al., "Single-Layer Dichroic Filters for Multifrequency Receivers at THz Frequencies," *IEEE Transactions on Terahertz Science and Technology*, vol. 10, no. 6, pp. 690-697, Nov. 2020.

[6] V. Desmaris, D. Meledin, A. Pavolotsky, R. Monje, and V. Belitsky, “All-metal micromachining for the fabrication of submillimetre and THz waveguide components and circuits,” *J. Micromech. Microeng.*, vol. 18, 2008, Art. ID 095004 (6 pp).

[7] Chao-Chun Chen, "Transmission of Microwave Through Perforated Flat Plates of Finite Thickness," *IEEE Transactions on Microwave Theory and Techniques*, vol. 21, no. 1, pp. 1-6, Jan. 1973, doi: 10.1109/TMTT.1973.1127906.